ICAS-84-0.5

ADVANCED MATERIALS IN PERSPECTIVE

R. L. Circle[1] and J. R. Carroll[2]
Lockheed-Georgia Company
Marietta, Georgia

Abstract

This paper presents an overview of Advanced Materials from the designer and material supplier point of view. Four major areas are covered: (1) a review of the material development process, (2) the potential payoff of advanced materials, and (3) introducing new materials and (4) future requirements of the marketplace.

A variety of advanced materials is now available and more are in various stages of development. There are several generic steps in the development process that all established materials have gone through and new materials are required to satisfy. These steps are discussed and specific examples are used to illustrate the development process.

It is shown that, of all the emerging technology advancements (such as engine, aerodynamics, electronics), the most significant payoff in the near future is likely to be from materials. The state of the art of organic composites and advanced metals is reviewed and relative advantages and disadvantages outlined. Specific payoffs to the operators are shown to be maximized when a combination of advanced materials is used.

Lastly, the future market for advanced materials is projected and related to potential new programs that will depend on material development success.

Material Development Process

There are more new aerospace materials coming into use or on the immediate horizon than at any time in recent aviation history. These materials range from improvements in ingot aluminum, such as lithium-aluminum, to drastically different material forms, such as graphite-epoxy composites. Obviously, the aircraft designer and manufacturer is uniquely challenged to keep up with this technology and be positioned to take maximum advantage of developments The payoff potential is of the same magnitude as was realized with the transition from wood/ fabric/wire structures to semimonocoque aluminum.

In spite of dramatic improvements in properties, a family of materials, rather than a single material, will continue to be used. The range of design requirements illustrated in Figure 1 will dictate the use of an optimum mix.

Irrespective of the form or properties, all advanced materials tend to follow a reasonably consistent series of steps. These steps can be viewed as a four-phase process as illustrated in Figure 2. In Phase I, the Investigation Phase, laboratory samples indicate the potential improvements available. A refinement process takes place to improve shortcomings. In Phase II, the Application Development Phase, preliminary design data is developed. This is also the time that studies begin to be conducted on the benefits of specific applications. Sample parts are made and tested to evaluate the processing and manufacturing characteristics. Long-term environmental conditions are simulated. The third phase is referred to here as the Secondary Structure Application phase. Design allowables are developed. Noncritical secondary structure is typically chosen for in-service evaluation of a small number of parts. During this in-service evaluation period, special and frequent inspections are conducted. After a sufficient evaluation period, secondary structure applications are committed to production. The final phase in the material development process is the application to primary structure. Full-scale testing is required, normally both ultimate strength and durability. In-service evaluation of primary structural components can then be conducted. The final step is commitment to production. Many of these steps can be skipped by accepting the accompanying risk.

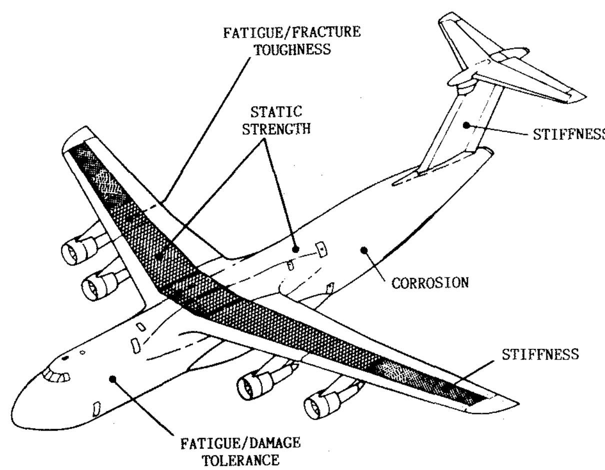


Figure 1. Material Selection

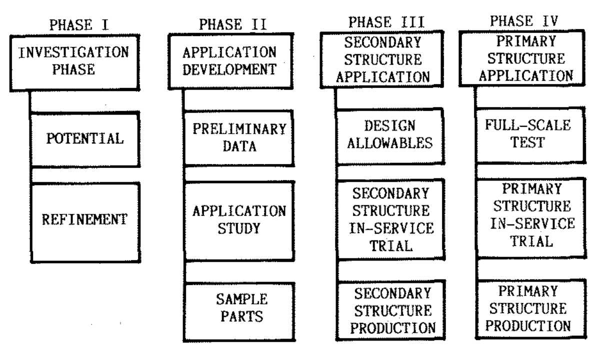


Figure 2. Generic Steps in Advanced Material Development

---

[1] Assistant to Chief Engineer-Research and Technology

[2] Staff Specialist, Advanced Structures

It is interesting to look at some specific examples of new materials going through their development cycle. Figure 3 traces the development of 7050 aluminum. Even though 7050 aluminum was a rather modest improvement in some design allowables compared to many of the materials now in development, it took about 20 years to complete the cycle. An unusual thing happened with 7050 when the first application occurred prior to full allowables being developed. The material was rushed into use to solve a problem with an in-service aircraft.

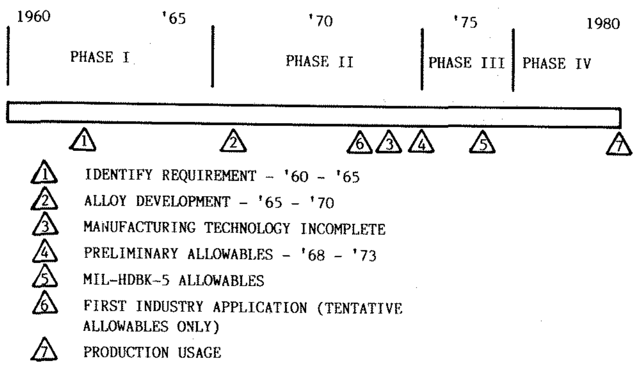


Figure 3. 7050 Aluminum Development Cycle

Organic matrix materials are a radical departure from conventional aluminum alloys in both design and manufacturing. Figure 4 traces the ongoing development of this class of materials. Application to the primary structure of fighters occurred about 20 years after development started. It appears that 30 years will be required to complete the application to transport primary structure. No steps have been skipped due to the completely different nature of the material.

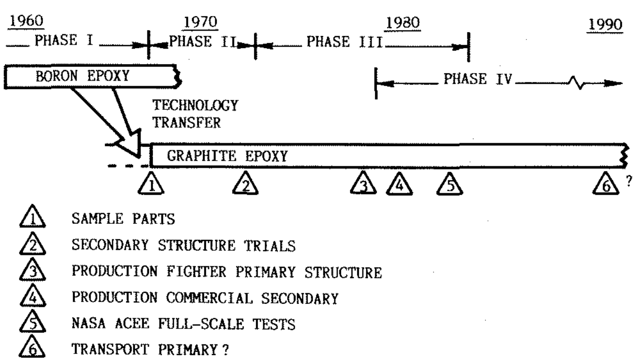


Figure 4. Organic Matrix Composites Development

Advanced Material Payoff

The relative payoff potential of today's advanced materials, compared to other technologies, is shown in Figure 5. These technology payoffs are consistent with other studies over the past years[1-4]. The unusual thing about this assessment, based on Lockheed studies of advanced technologies,[5] is that for the first time in modern history the structures and materials development will result in the major improvement. In the past, propulsion technology has led all technologies in aircraft improvements. The two most recent examples of this are the advent of the turbojet in the 50's and then the high-bypass-ratio fanjet in the 60's. The technology payoffs are evaluated by studies that follow the elements shown in Figure 6. Beginning with mission requirements, the baseline aircraft and the advanced aircraft are sized to give equal airlift capability. Resizing benefits are included. Resizing is the accounting for benefits on one component due to reduction in a different component. An example would be a reduction in landing gear weight due to a wing weight reduction. This resizing benefit can double the overall benefits.

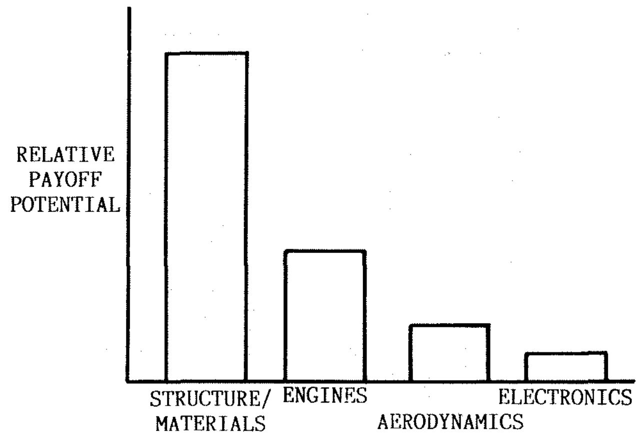


Figure 5. Technology Payoff Assessment

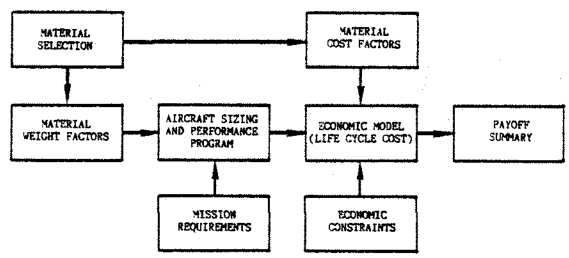


Figure 6. Study Plan

The aircraft shown in Figure 7 will be used to illustrate the benefits of some of the new materials now on the horizon. This large transport is referred to as the ACMA, i.e., Advanced Civil/ Military Aircraft. The possibilities for this program were studied by Lockheed-Georgia.[6] As shown, it is a 1M lb. gross weight aircraft and is visualized as a potential C5A/B747 replacement. The weight reduction benefits for maximum use of graphite/epoxy composite materials on the ACMA is shown in Figure 8[7]. The crosshatched areas represent the increased weight savings from the benefits of resizing mentioned previously. It should also be noted that the "maximum" graphite/ epoxy aircraft is about 55% graphite epoxy of the aircraft structural weight. About 45% of the weight is in structure where graphite epoxy is not appropriate, such as heavy frames and landing gear.

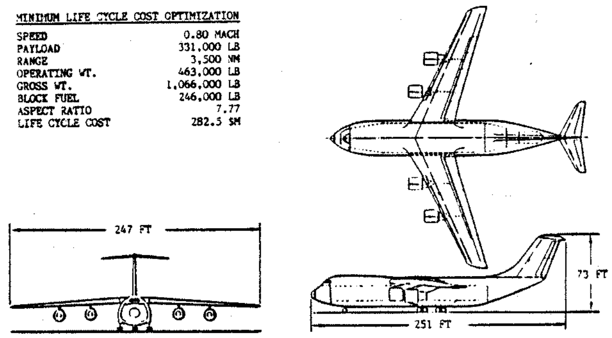


Figure 7. Future Large Transport - ACMA

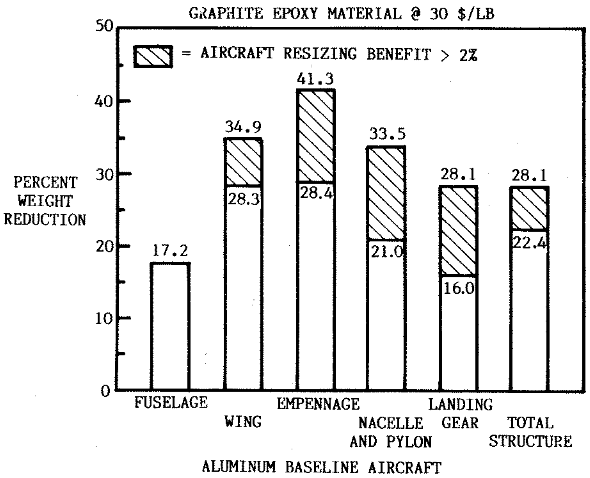


Figure 8. Graphite Epoxy Aircraft Benefit Summary

A comparison of the payoff of several advanced materials is shown in Figure 9. Maximum use of each material is assumed in these comparisons. This assumption is useful for comparisons; however, the optimum airframe would be a combination.

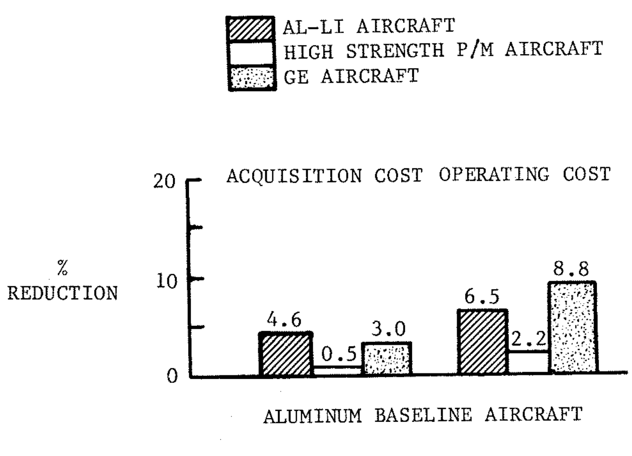


Figure 9. Advanced Material Comparisons

Introducing New Materials

The decision process in the selection of new materials is not a simple process and necessarily includes a great deal of judgement, as well as technical data. The decision process is fundamentally a series of tradeoffs between Risk, Payoffs and Impact on the system. This tradeoff process is illustrated in Figure 10.

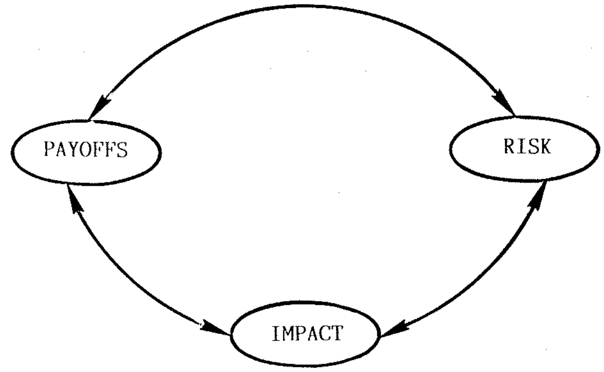


Figure 10. Decision Process in New Material Introduction

The payoffs are the easiest factor to assess technically. Performance improvements, acquisition and operating cost differences can usually be projected with a high degree of confidence.

The Risk factor is significantly subjective and involves judgement of the adequacy of the material property data base, level of experience with the material both in test and in service.

The Impact factor is measurable, but sometimes overlooked. Graphite epoxy composite is a good example of a material with a large impact on facilities, trained or untrained personnel, and maintenance differences for the user.

There are times where performance payoffs dominate, particularly on fighter aircraft, but this is rarely the case on transports.

One of the attractive aspects of advanced aluminums compared to graphite epoxy is the relatively low facility costs. The relative difference in facility costs between graphite epoxy and advanced aluminum for an average size transport wing is illustrated in Figure 11.

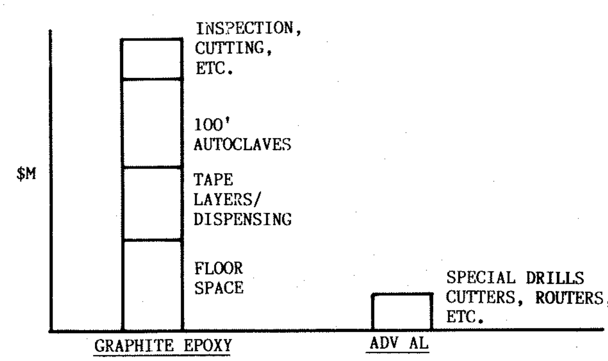


Figure 11. Facilities Cost Comparison Transport Size Wing Box Covers/Spars

Tens or hundreds of millions of dollars must be spent for new facilities and equipment for non-metallic composites. Virtually, a new and different factory must be created. Most of the advanced metallic materials by comparison required only special drills, cutters, etc. This facilities factor is not a trivial problem, especially if the cost of the new facilities must be amortized over the life of the first product.

Relative prices of different materials obviously have a tremendous effect on the decision on which material to use. The payoffs described in Figure 9 come from estimates of producers with certain assumptions about future market volume. The accuracy of these assumptions is important. Figure 12 show the history of graphite fiber price for the last 15 years in then year dollars. The reduction is dramatic especially considering inflation would have more than doubled the price over the last ten years if all else remained constant! Figure 13 is a companion to Figure 12 and shows the total market for fiber over the years. Obviously, the increased market has helped reduce the price. Aerospace use is running about one-third the total fiber market.

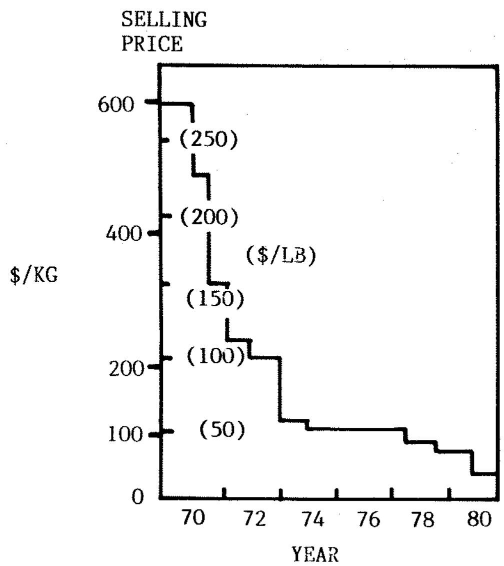


Figure 12. Graphite Fiber Price History

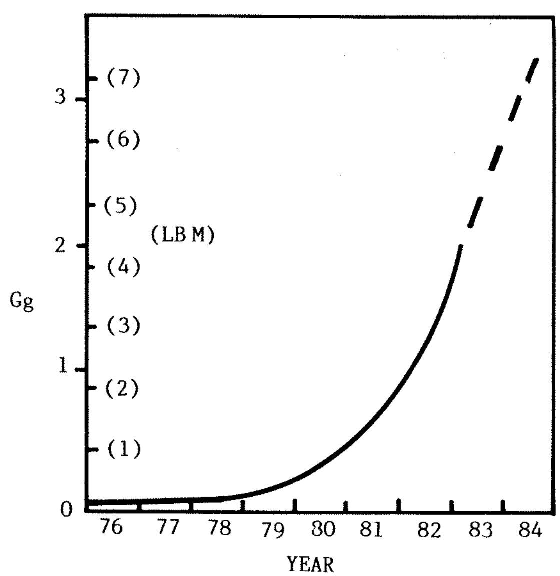


Figure 13. Graphite Fiber Total Market

Future Requirements

You can speculate from Figure 13 where graphite epoxy use is headed; however, further dramatic price reductions such as we have seen in the past do not seem likely. The boom in the use of of composites has challenged the metals industry. Improvements in advanced metals definitely provide an option to the designer. A recent study for NASA[8] on the payoff of advanced metals forecasts the market shown in Figure 14.

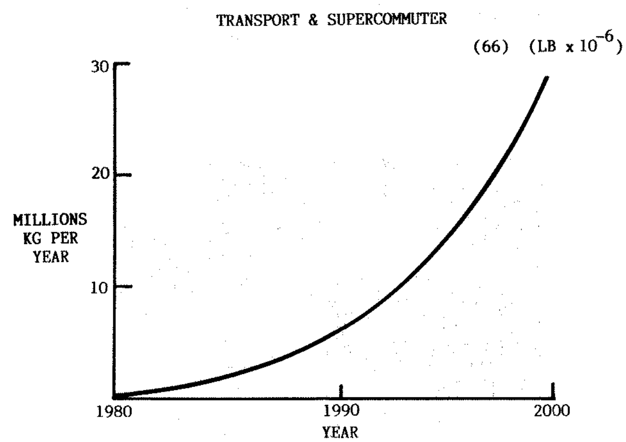


Figure 14. Potential Advanced Metals Use Forecast

The projected material usage for a future large transport of about the late 1980's is shown symbolically in Figure 15. Aluminum, improved and advanced, would run at least one-half. Composites should at least 20%. Other materials, such as steel and titanium, would run about 10%. Depending on developments over the next couple of years, about 20% could go either way - composites or advanced aluminum, including aluminum matrix composites. Most of this difference would depend on the decision on the material for the wing box.

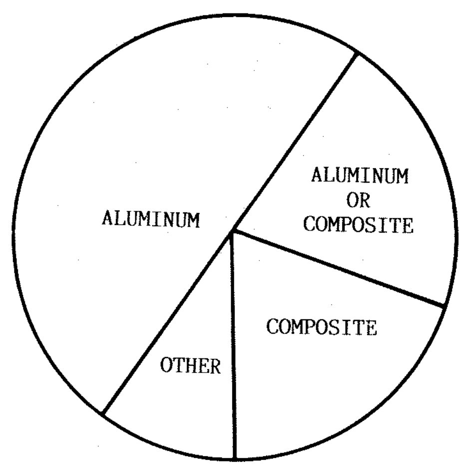
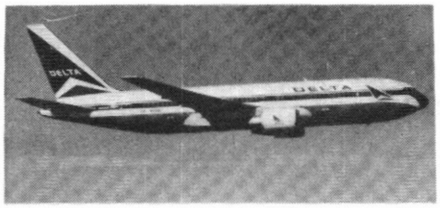
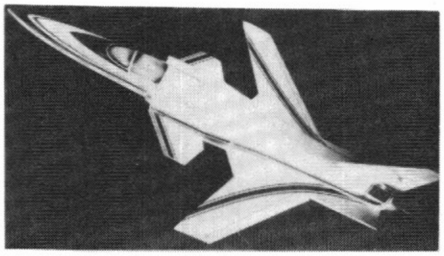


Figure 15. Projected Material Usage-Future Large Transport

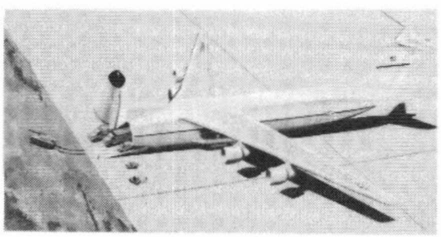
There are requirements for several aircraft now in the early planning stages. These aircraft are represented in Figure 16 and are the Delta B commercial transport, the Advanced Tactical Fighter and the ACMA. Near-term material developments are so important to achieving the cost and performance goals of all of these aircraft that these programs may actually hinge on material developments. It should be emphasized on the transports that cost factors may override the performance factors.[9]



DELTA B - NOW?



ADVANCED TECHNOLOGY FIGHTER



ACMA - 2000

Figure 16. Future

Summary

What material? The details of this decision carry an importance today and in the foreseeable future as never before. Many of these material decisions effect manufacturing as never before. The materials used will be a combination as illustrated in Figure 17, also as never before. More choices mean more differences and more optimization. More optimization will lead tc more efficiency for the benefit of all.

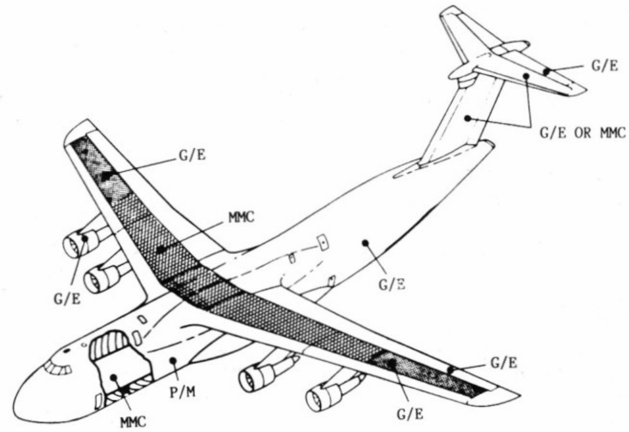


Figure 17. What Material?

References

1. Kramer, J. J., "Planning a New Era in Air Transport Efficiency," Astronautics & Aeronautics, July/August 1978.

2. Conner, D. W., "CTOL Concepts and Technology Development," Astronautics & Aeronautics, July/August 1978.

3. Leonard, R. W., "Airframes and Aeronautics," Astronautics & Aeronautics, July/August 1978.

4. Nored, D. D., "Propulsion," Astronautics & Aeronautics, July/August 1978.

5. Lange, R. H., "Trends in Very Large Aircraft Design Technology," AIAA Paper 80-0902, Baltimore, Md., May 1980.

6. Mikolowsky, W. T., and Garrett, W. A., "Joint Civil/Military Cargo Aircraft," AIAA Paper 80-1052, Amsterdam, September 1980.

7. Lange, R. H., and Moore, J. W., "Systems Study of Applications of Composite Materials for Future Transport Aircraft," AIAA paper 82-0812, Washington, D.C., May 1982.

8. Sakata, I. F., "Systems Study of Transport Aircraft Incorporating Advanced Aluminum Alloys," NASD Contractor Report 165820, January 1982.

9. Circle, R. L., Lassiter, L. W., Meadows, D. M., "Transitioning Composites Into The Primary Structure of Cargo Transport Aircraft," SME Paper EM-106, Anaheim, CA., January 1984.